PPS GPS Non-Precision Approach Demonstration in a Navy HH-1N

CAPT Paul M. Novak, *USN*
CDR Mark Gonzalez, *USN*
John Praktish, *DCS Corporation*

Space and Naval Warfare Systems Command
Navigation Systems Program Office - PMW 187

BIOGRAPHY

Captain Paul Novak was raised in Connecticut, and in 1973 he received a B.S. in Biology from Stonehill College, North Easton, MA. He is a graduate of the Aviation Officer Candidate School, and was designated a Naval Aviator in 1975.

His first assignment was with Helicopter Anti-Submarine Squadron Eight at NAS Imperial Beach, CA, where served as a pilot for the SH-3D "SEA KING" helicopter and deployed aboard the aircraft carrier USS KITTY HAWK. After this assignment, he attended the Naval Postgraduate School in Monterey, CA, and was awarded a Masters of Science in Computer Systems Management in 1980. In December 1980 he reported to Helicopter Anti-Submarine Squadron Two, in San Diego, CA where he flew the SH-3H "SEA KING" helicopter, and deployed aboard USS RANGER. He received the Navy Achievement Medal for a night rescue of 5 aviators in the Persian Gulf in 1981. In 1983 he reported to the Chief of Naval Operations, Washington, DC, as project officer on a Navy mainframe computer system.

In 1984 he was designated an Aerospace Engineering Duty Officer, and reported to the IBM Federal System Division facility in Owego, New York, as SH-60B "SEA HAWK" Flight Acceptance Test Pilot, and Naval Air Systems Command Program Managers Representative for the Light Airborne Multi-Purpose System (LAMPS) MK III Program. In 1987 he reported to the Naval Air Systems Command Headquarters in Washington, DC, as the Avionics Systems Project Officer for the LAMPS MK IIL/SH-60B, and the VH-3D and VH-60N Presidential

Helicopters. In 1990 he completed the Program Managers course at the Defense Systems Management College, FT Belvoir, VA, and was reassigned to the Naval Air Development Center, Warminster, PA. , as the Director of the Vertical Flight Division. At NADC he led a team of 50 scientists and engineers delivering hardware and software products to the fleet and to various Naval Air Systems Command Program Offices. In 1993 Captain Novak reported to the Space and Naval Warfare Systems Command, Washington, DC, where he directed the integration of Global Positioning System into 86 different kinds of U.S. Navy, Marine Corps, and Coast Guard aircraft. On 14 June 1996 he assumed command as Program Manager, Navigation Systems at the Space and Naval Warfare Systems Command where he is responsible for the integration of GPS into all U. S. Navy, Marine Corps and Coast Guard aircraft, and the Navy ships and submarines.

His personal decorations include the Meritorious Service Medal (two awards), the Navy Commendation Medal (two awards), and the Navy Achievement Medal. He is a designated Acquisition Professional.

Commander Mark Gonzalez was raised in the San Francisco Bay area, and in 1980 received a Bachelor of Science degree from the United States Naval Academy. He attended flight school at Naval Air Station Pensacola and was designated a Naval Flight Officer in 1981.

Upon completion of training at the A-6E Fleet Replacement Squadron (FRS) at Whidbey Island, Washington he was assigned as a bombardier navigator with VA-115, forward deployed with the USS Midway

and homeported in Yokosuka, Japan. His next assignment in 1985 was as a FRS Instructor for the A-6. In January 1986 he reported to the U.S. Naval Test Pilot School where graduated in 1986. Among the few to be designated to fly developmental aircraft, CDR Gonzalez reported to Calverton Long Island where he participated in the flight testing of the A-6E aircraft.

In 1988 he reported to the Pacific Missile Test Center where he assumed the responsibilities for the flight testing of the Tomahawk missile.

In 1989, he reported to Commander, Cruiser Destroyer Group Five, where he performed the duties of Strike Operations Officer and (acting) Air Operations Officer. In 1990, he was ordered to Riyadh, Saudi Arabia and was assigned to IFACC where he was responsible for the integration of Tomahawk missile into the Offensive Air Campaign of Operation Desert Storm.

In 1982 he reported to the Naval Strike (and Air) Warfare Center, Naval Air Station Fallon.

In 1994 he attended the Naval Postgraduate School in Monterrey, California where he was awarded a Masters of Science degree in Computer Science.

In 1996 he reported to the Space and Naval Warfare Systems Command where he directed the integration of the Global Positioning System into over 100 different kinds of U.S. Navy, Marine Corp and Coast Guard Aircraft.

In May of 2000, CDR Gonzalez will report to PEO (Cruise Missiles) where he will assume duties with PMA-281, the Tomahawk Command and Control Program Office.

His personal decorations include the Bronze Star, Air Medal (with Bronze Star) and the Navy Commendation Medal (4).

John Praktish is a 1985 graduate of the State University of New York Maritime College with a Bachelor of Engineering Degree in Electrical Engineering and a USCG Third Mates License, Unlimited Tonnage, Unlimited Oceans. He performed checkout and acceptance test operations on the B-1B's avionics and flight controls systems for Rockwell–North American. He developed advanced flight control system/man machine concepts for Northrop's Advanced Tactical Fighter Full Scale Development program.

He has provided program management and system engineering support to the U. S. Navy's NAVSTAR Global Positioning System (GPS) aircraft integration program since 1990. Mr. Praktish is an employee of DCS Corporation at San Diego, Ca.

ABSTRACT

Following the tragic 1996 death of the Honorable Ron Brown, Secretary of Commerce, in a USAF CT-43A, Dr. Paul Kaminski (USD A&T) and General Ralston (VCJCS) directed the services to come up with a plan to implement a GPS capability for world wide use, that would allow flight enroute, terminal, and non-precision approach in instrument conditions. The U.S. Navy funded a project to develop all necessary aspects for this capability and then conducted extensive ground and flight test of the total system in an HH-1N helicopter equipped with a Precise Positioning Service (PPS) GPS receiver and integration. This paper will cover the history of the project, the details of the design, and analysis of the resulting Developmental and Operational Test reports. Conclusions as to the merit of implementing this design in operational USN and USMC aircraft will be evaluated.

INTRODUCTION

GPS provides a worldwide positioning, velocity and timing capability to an unlimited number of users, at unprecedented levels of accuracy.

All editions of the Federal Radionavigation Plan (FRP) and the JCS Master Navigation Positioning and Timing Plan (MNPTP) since 1980 have indicated that the Department of Defense (DoD) intends to phase out the military's requirement for VOR/DME and land based TACAN. The ability to use GPS as the primary means of navigation for DoD aircraft world-wide continues to be a principal objective in the integration of GPS capability into military aircraft.

Prior to 1988 the U.S. National and International Airspace consisted of airways established by fixed radio-navigation aids. The airways are established by VOR/DME (VHF Omnidirectional Range/Distance Measuring Equipment) and TACAN (Tactical Air Navigation) stations. Each station provides bearing and range to a known location. The bearing from a station to an aircraft is known as a radial.

VOR/DME and TACAN stations have an identifier, frequency and or channel associated with them. Aircrews tune their VOR/DME/TACAN receivers to the appropriate frequency/channel for reception of the signals.

The radio-navigation aid's radials form a series of interlocking "highways in the sky" enabling aircraft to travel from point to point.

Figure 1.
Pre-existing National Air Space Structure

A single radionavigation aid defined the approach, most often consisting of a DME arc to an inbound radial (ref. Fig 2).
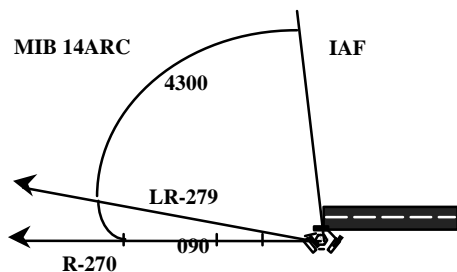

Figure 2.
TACAN Approach

BACKGROUND

In 1988 the Assistant Secretary of Defense Command, Control, Communications and Intelligence (C3I) formally directed the services to integrate GPS in such a manner as to emulate TACAN/VOR/DME.

The airways structure was analyzed where it was determined that three basic navigation modes would support emulation of VOR/DME/TACAN.

Those three navigation modes are;

To-To, where two points define a unique Geodesic path, bearing and distance is to the destination point, cross track error is referenced to the desired Geodesic path.

Direct-To, substitutes aircraft present position at time of activation for the source point.

To-From, utilizes a single point with a user-defined course To or From the destination. The user-defined course is based on the magnetic variation to which the navigation aid is aligned.

Scaling of the cross-track deviation indicator was derived from the widths of the airways. The selected scaling is; Enroute $\pm$ 4.0 NM, Terminal $\pm$ 1.0 NM, Approach $\pm$ 0.3 NM.

The width of the airways measured against the flight instrument error and flight technical error determined the limits on when GPS could or could not be used for navigation. The error limits are directly linked to the CDI scaling to provide a comprehensive system that provides the aircrew the necessary information to maintain the aircraft within the Primary Obstacle Clearance area. The Primary Obstacle Clearance area is defined as the area within which 95% of the flights with aircraft using the authorized navigation source will be contained.

State aircraft are self-certifying for operation within the National and International Airspace per international agreement as recognition of their unique mission. In the 11 May 1988 ASD C3I memo, subject: Integration of Global Positioning System (GPS) to Fly in the National Airspace, ASD C3I requested the Air Force to develop multi-Service minimum operational performance standards (MOPS). The MOPS provide the guidance on the required capabilities to be integrated into the aircraft for them to able to operate safely within the prescribed airspace.

ASD C3I approved the Minimum Avionics Requirements (MAR) 13 September 1991, the approved version of the MOPS. On 12 October 1993 ASD C3I cancelled the MAR in favor of service specific guidance. Subsequently the Chief of Naval Operations approved the CNO GPS Integration Guidance (GIG) document 06 May 1994. The MAR and CNO GIG define the precise requirements for integrating GPS into DoD and DoN aircraft respectively. The adoption of these standards provided a consistent level of functionality and a means by which the test community can validate the aircraft integration of GPS for flight in the National Airspace.

The requirements as stated in the MAR and CNO GIG were analyzed with respect to existing Department of the Navy (DoN) navigation architectures. It was determined that several deficiencies existed. These deficiencies formed the core requirements that GPS avionics must address through integration of discrete elements.

To do this functionality was allocated to the elements that provide processed information on a standardized data bus. The elements are:
- Portable Memory device
  - Flight Plans
  - Aeronautical Data
- GPS Receiver
  - Position, Velocity, Time

- ♦ Accuracy of data
- ♦ Navigation Computer
  - ♦ Bus Controller
  - ♦ Full Alpha-Numeric keypad
  - ♦ Programmable function keys
  - ♦ Text Display
  - ♦ Line Select Keys
  - ♦ Graphical Processor
- ♦ Digital to Analog Converter
  - ♦ Interfaces with analog flight instruments

U.S. NAVY GPS AVIONICS AND MISSION PLANNING

The Navy developed an integrated, modular avionics suite, designed for robustness and growth without requiring major redesign efforts.

Central to that is the Control Display Navigation Unit (CDNU), which provides a full alphanumeric keypad, mission computer functionality, MIL-STD-1553B and ARINC 429 data bus, and discrete I/O interfaces, enabling it to effectively replace other cockpit control heads. CDNU integration costs are 1/3 that of mission computer costs with a 75% shorter development and test schedule.

As validation that the modular system permits component upgrade without major redesign the ASQ-215 Digital Data Set (DDS) recently underwent a Value Engineering Change Proposal (VECP). The VECP for the DDS, changed the memory from EEPROM to Flash memory. Form was changed from a single solid-state memory device to one capable of accepting and utilizing PCMCIA cards. This permits memory to increase to the maximum size of present day PCMCIA Flash cards. Flash memory is a growing technology as compared to EEPROM which is at mature/static state. Changing the form factor to accept PCMCIA cards with a controlled government interface takes advantage of industry growth patterns without the burden of requiring aircraft systems to continually change, i.e. chasing technology. The mass memory provided by FLASH coupled with innovation permits information synthesis for Terrain Awareness Systems.

Figure 3 is the baseline architecture that meets the CNO GIG requirements.

CONTROL DISPLAY NAVIGATION

DIGITAL DATA SET (DDS)

ARINC 429

RECEIVER GPS

D TO A CONVERTER

ANTENNA

ANALOG FLIGHT INSTRUMENTS

MIL STD 1553 BUS

Figure 3.
Common CDNU Architecture

The Digital Data Set (DDS) ASQ-215 provides a secure means to transfer flight information to the cockpit allowing the aircrews to pre-plan their missions. The DDS is also a repository of general aeronautical information permitting the flexibility of rerouting in flight.

A Digital to Analog Converter, officially known as the GPS Signal Data Converter (SDC) CV-4138/A converts ARINC 429 outputs to analog and discrete signals for interfacing with analog flight instruments and display of annunciations.

The U.S. Navy's mission planning system provides a ground-based ability to plan flights from take-off through recovery. The underlying aeronautical database is the National Imagery and Mapping Agency's (NIMA) Digital Aeronautical Flight Information File (DAFIF), distributed every 28 days. Airways are depicted on the mission planning system and can be incorporated into a flight plan by selecting in order the waypoints that form the routes. A subset of the DAFIF database can be created and loaded into the DDS supporting rerouting in flight.

CHANGING REQUIREMENTS

03 April 1996, Secretary of Commerce, Ron Brown's aircraft was lost on approach into Dubrovnik. Questions arose pertaining to aircraft safety. Vice Chairman of the Joint Chiefs of Staff (VCJCS) in conjunction with the Under Secretary of Defense (Acquisition and Technology) (USD A&T) initiated several safety programs for DoD passenger carrying aircraft. The safety programs consisted of requiring the equipage of passenger carrying aircraft with Interim Portable GPS for situational awareness by the end of 1996, acceleration of GPS installations on passenger carrying aircraft, and adding voice and flight data recorders to VIP carrying aircraft. 06 June 1998 VCJCS and USDA&T issued the memo directing the GPS Phase In Steering Committee to determine the actions necessary, beginning in 1998 to enable DoD aircraft to take off, fly and recover to non-precision approach minimums anywhere in the world without reference to ground based navaids. The U.S. Navy's GPS Non-Precision Approach program was initiated in response.

Between 1988 and 1996 the requirement for the use of GPS in controlled airspace underwent rapid change. The level of integrity, the ability to determine when a navigation source is suitable for it's intended use, previously undefined, was defined for civil systems as the Probability of Unalarmed Hazardously Misleading Information (PUHMI). Often stated as a per hour requirement.
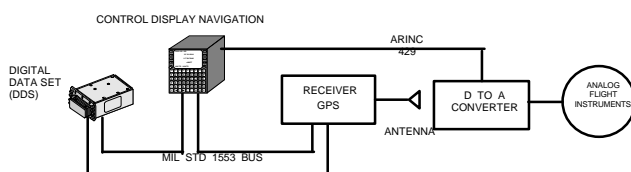
GPS NPA was redefined from an overlay of existing VOR/DME/TACAN procedures to a unique sequence of waypoints. The FAA to capture the new GPS functionality issued Terminal Instrument Procedures (TERPS) 8260.38a, and TSO-C129. Initial reports on the civil implementation of TSO-C129 indicated several operational drawbacks, principally in the area of human factors.

In pursuit of GPS based navigation becoming a Sole Means system, the FAA continued their development of the Wide Area Augmentation System (WAAS) Minimum Operational Performance Standards (MOPS) through the RTCA. Concurrent with the development of the WAAS MOPS, FAA Flight Standards investigated potential changes to TERPS based on the forecast WAAS capabilities. WAAS was conceived to augment GPS for civil users providing greater availability of accuracy and integrity

NPA PROGRAM

To fulfill the objectives of the VCJCS and USD A&T memo PMW-187 needed to capture these and other changes in a manner that would enable a cost effective implementation that complements the military mission.

With evolving requirements a thorough analysis of the operational benefit of each requirement vs the impact of implementing the requirement must be thoroughly understood. PMW-187 established a process for the examination of these requirements utilizing an Integrated Program Team.

The first step in establishing an IPT is the identification of the functional areas and interfaces that a program will involve. Representatives of those areas form the core IPT. In selecting individuals desirable traits are; knowledge of area, involvement in developing future requirements, and commitment to the common goal of the IPT. The functional areas for GPS NPA are:

- Procedure Construction
- Aeronautical Databases
- Mission Planning Systems
- Data Transfer, ground to aircraft
- GPS
- Aircraft Databus (MIL-STD-1553B, ARINC 429)
- Navigation
- Controls and Displays
- Systems Engineering
- Human Factors
- Program Management

To define an end solution that is acceptable, the appropriate quantifiable measures of success must be determined at program inception.

The key performance measure for GPS NPA is to be able to safely fly within the primary obstacle clearance zone. In the changing airspace how the zone is defined and will be defined drives the solution. The error sources for human controlled flight were examined, where it was determined that the leading error source was flight technical error (FTE). After a thorough literature search of technical papers, test results and leading edge research, the only apparent consistent way to reduce FTE was through the use of automation, i.e. the computer must fly the aircraft. This is impractical from a cost standpoint for all aircraft to adopt auto pilot/flight director systems. The ultimate limit on the Primary Obstacle Clearance area construction is not the navigation solution but rather the man in the loop who must be able to consistently fly the approach procedures as published. Proposals to drastically alter the airspace were analyzed in this light. Therefore Terminal Instrument procedures (TERPS), 8260.38a was adopted for the GPS NPA program as the definitive primary obstacle clearance area that the aircraft must be able to operate safely with in.

Figure 4, as an example of the Primary Obstacle Clearance areas, depicts a straight in procedure using the criteria set forth in TERPS 8260.38a, the four stars are from left to right, the Initial Approach Fix (IAF), Intermediate Approach Fix (IF), Final Approach Fix (FAF) and Missed Approach Point (MAP). The Primary Obstacle Clearance area transitions from $\pm$ 4.0 NM (IAF) to $\pm$ 2.0 NM (IF), $\pm$ 1.0 NM at the FAF and $\pm$ 0.5 NM at the MAP. 8260.38a is not limited to straight in approach procedures.
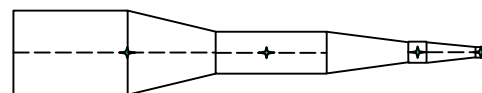

Fig 4.
Primary Obstacle Clearance Area
Straight In Approach

Acceptance by the fleet is the second and no less important key performance parameter. To insure fleet acceptability of the design COMOPTEVFOR (COTF) and fleet operators reviewed the initial requirements and system design. COTF and fleet operators participated in the development process at each major system review culminating in the flight tests.

The objective in the design was to be fleet representative. Selecting a demonstration instead of a full Development Test (DT) provided the flexibility to incorporate required changes through out the process while insuring a thorough flight test program.

MAINTAINING FLIGHT INFORMATION PRODUCTS IN THE COCKPIT

Existing approach plates provide a graphical representation of the approach with detailed static information. The option to replace the paper approach plates was examined and dismissed. Aircraft have a limited amount of display surfaces, particularly older aircraft. FLIP space is presently accommodated on aircraft. The modification of the FLIP display space often will not support a flat panel display as that the approach plate is often placed on the yoke or kneeboard. To accommodate a new display would require the redesign of the aircraft displays and integration of existing flight information into an undetermined format. Qualification, procurement, integration and installation of a new graphical display system poses significant risk to both schedule and cost when considered for 1310 aircraft, especially in light of only marginal performance improvements in FTE.

NIMA products at present do not contain digital approach plates further complicating the problem.

Finally there is the memory impact for graphical displays on data transfer products.

NPA SELECTION

The pilot designates the airfield as the destination, selecting F5 provides a display of the available runways with GPS NPAs at that airfield. The pilot can select the appropriate runway with the line select key located next to the entry. By minimizing the distance between selection key and selection, the time to select the runway is reduced, as is the amount of required eye movement and refocusing. The line select keys eliminates the possibility of typing in the incorrect procedure name.

After runway selection the available Initial Approach Fixes (IAF) are displayed in an identical manner. The procedure name is displayed as airport/rwy/IAF at the top of the display as each item is selected. When airborne a confirmation of the desired procedure is required to prevent inadvertent acceptance of procedures. The accept key is deliberately placed on a separate part of the screen to force the aircrew to refocus and make a conscious acceptance of the procedure, i.e. prevent accidental striking of the same key twice.

TERMINAL AREA OPERATIONS

The terminal arrival area concept maintains a 30 NM radius centered on an airfield. To insure interoperability with emerging standards this 30 NM radius is applied to the NPA software. Airfields that are labeled as DEST will cause the Control Display Navigation Unit (CDNU) to transition to Terminal area sensitivity for both the cross track deviation indicator and the integrity limits (1 NM) when within the 30 NM circle, provided that a GPS NPA

procedure has been selected and accepted. If the airfield is labeled a DEST and a procedure has not been selected and accepted the NO APPROACH annunciation is provided when within 30 NM of the DEST airfield. For operations around an airfield, for example NAS Fallon the DEST label is removed by aircrew action preventing nuisance alerts. The CDNU provides the capability for non-NPA points to manually select CDI scaling to either Enroute, Terminal or Approach, $\pm$ 4 NM, $\pm$ 1 NM and $\pm$ 0.3 NM respectively. For NPA the CDI scaling and integrity limits are linked to insure that the aircraft remains within the cleared airspace providing the Required Navigation Performance (RNP).

EXECUTING THE PROCEDURE

The default for flying the procedure is automatic waypoint sequencing. Human Factors analysis indicated a reduced workload during the approach phase of flight with no degradation of situational awareness, makes this a desirable choice.

The ability to hold at any point except the MAP is provided by utilizing the pre-existing holding procedures in the CDNU. This is a difference from some Flight Management Systems, which automatically hold at each holding point, requiring aircrew intervention to continue the procedure, and subsequently increasing the aircrew's heads down time.

CDI/Integrity scaling transitions at 30 NM to the Missed Approach Point from Enroute to Terminal scaling. The second transition occurs when within 2 NM of the Final Approach Fix. Both are funnel type transitions occurring over 1 NM of flight. A funnel transition was selected to reduce potential large CDI swings that may lead to over correction and hunting of the CDI during an approach.

At the Missed Approach Point the CDI/Integrity scaling is a step change to Terminal scaling where it remains until the Missed Approach Holding Point (MAHP). Automatic sequence of the waypoints ends at the MAHP.

The decision to deviate from all angular guidance was based on present CDNU operations, structure of the airspace on an approach and simplification of aircraft corrections. Presently the CDNU operates using fixed non-angular scaling. The benefits of redesign and retraining would be negligible.

8260.38a TERPS are primarily rectangular; the CDI accurately depicts the aircraft's position within that rectangle. Aircrews do not need to consider approaching or receding from the apex of the cone in course corrections, this simplifies by one element required course corrections and is in consonance with RNP concepts.

Approach points can not be inserted, deleted or modified.

ALTERNATE MEANS OF PROCEDURE EXECUTION

Procedure flexibility is provided by three functions, Direct-To any point in the procedure except the MAP, Vectors to Final, and the ability to specify an inbound course to the IAF. These functions are to allow Air Traffic Control and aircrews the ability to adapt to changing conditions.

All alternate means of procedure execution require the previous acceptance of the procedure.

Direct-To defines the course from present position at time of activation advanced for turn anticipation to the selected point. Scaling remains dependent on distance to FAF.

Vectors to Final are an extension of the course from the FAF to the MAP. Bearing and distance are to the FAF until the FAF is sequenced.

The ability to specify an inbound course to the IAF is a manually entered value.

DATA PROVIDED ON THE CDNU

The CDNU displays the following information:
Waypoint Name
Waypoint Identifier (IAF, IF, FAF, MAP, MAHP)
Altitude
Altitude Description (At, At or Above, At or below)
Fly-by, Fly-over, used to provide or inhibit turn anticipation
Turn Direction (left or right)
Bearing and Distance to any point in the procedure
Latitude/Longitude of all points in the procedure

Information not provided on the CDNU:
Minimum Descent Altitude (aircraft dependant, displayed on Approach Plate)
Minimum Sector Altitude (displayed on Approach Plate)

MODIFICATIONS

GPS SDC's in the inventory were modified to provide an integrity alert annunciation in the primary field of view. An integrity annunciation without the navigation and DME warning flags in view indicates that the integrity of the navigation solution can not be determined, it does not necessarily mean the navigation solution is in error. An integrity annunciation with the navigation and DME warning flags in view indicates that the navigation solution is unsuitable for the present phase of flight based on a failure detected by the integrity functionality. The functionality described reflects the functionality in ICD-

GPS-073. The modified SDCs were production representative.

A Miniaturized GPS Receiver (MAGR) with integrity was unavailable. An Enhanced MAGR test unit used in FAA and PMA-213 tests, containing integrity was supplied for use by PMA-213. The EMAGR was not production representative but provided the required functionality to support end-to-end testing of the system. Without production representative hardware a DT could not be performed.

INTERFACES

Controlling and understanding the interfaces is the capstone to establishing a functional design. Whether it be the Apollo spacecraft which minimized the number of interfaces between stages to reduce the probability and promulgation of errors or GPS NPA where the interfaces were well understood and controlled to prevent errors, clear well defined interfaces are fundamental to success.

The use of aeronautical databases as the basis for non-precision approach creates the potential for catastrophe if the interfaces from data creation through aircraft upload are not controlled and data integrity is lost. This was a contributing factor in selecting a series of flight tests instead of a full DT. Data handling must not degrade the safety of the aircraft below that of the navigation system.

Data can not be corrupted during the mission planning cycle. Mission Planning software development requires 2-3 years from development to fielding. Prototype software was developed outside of the mission planning development cycle to validate the correct coding prior to implementing in a fielded Mission Planning System. The prototype provides a test tool for comparison to the MPS product, insuring data is not corrupted. It also provides the psuedo-code for MPS developers.

The ability to remove approach procedures from the useable database due to NOTAMS is an emerging MPS requirement. Manually altering of the approach data is prohibited due to the potential for human error.

The Chief of the Naval Flight Instrument Group, Mr. Bob Lesperance was instrumental to the success of the program. As the person responsible for Department of the Navy TERPS and chairman of the Digital Aeronautical Flight Information File (DAFIF) working group he provided unique insight into the creation of GPS NPA procedures, information flow from surveys through approach creation and publication in DAFIF. His position and knowledge enabled the interfaces to be well understood and controlled.

Working through the DAFIF users group and with the help of NAVFIG as well as many others, the aeronautical data elements that directly effect flight safety were identified. The required probability of correctness was assigned to each item. Criteria for NOTAMs were developed, i.e. allowable error before a NOTAM must be issued. NIMA is now required to develop metrics that demonstrates that DAFIF meets or exceeds the required level of safety.

DAFIF procedures (approach, SIDS, STARS) are not assembled in the primary DAFIF file, they do not appear as a single contiguous list that can be selected and downloaded to the aircraft. Assembling the procedures correctly requires software developers to correctly code the key fields for procedure reconstruction. To insure successful software development the DAFIF dictionary is being modified to include flow diagrams, clearly illustrating the relationships between data.

Host country data accuracy and integrity is the domain of ICAO where progress continues to made in insuring data accuracy and integrity.

TESTING

Human Factors was identified as a key performance area and addressed by three methods. The application of DOD-HDBK-763, Human Engineering Procedures Guide, 27 February 1987 mission profiling for development of the initial design. The Patuxent River Naval Air station simulator was used to confirm the acceptability of the implemented design prior to flight test. Flight-tests at Patuxent River, with COMOPTEVFOR and fleet pilots participating, validated the system design as integrated into an aircraft.

Human Factors Analysis profiled the mission as it transitioned from enroute through NPA using techniques listed in MIL-HDBK-763 Human Engineering Process Guide. The mission profile detailed the tasks pilots would be performing during the mission, where their attention would be, work load sharing in multi-person cockpits, how much time would be spent on each task, information required, time to assimilate and the time to act on information.

In each stage of development higher fidelity testing was utilized. Using the Patuxent River Manned Flight Simulator a series of non-precision approaches were conducted by a variety of fixed and rotary wing aircrews. Actual CDNU flight hardware was integrated into the fixed base simulator. Simulator testing was utilized to assess software maturity, ease of use, workload, and functionality.

The flight test portion was made up of ground and flight tests of approximately 40 and 24.1 hours respectively. Test flights consisted of 22 approaches at NAS Patuxent River and 1 approach at Langley AFB. The tests focused on the ability of pilots to safely perform GPS NPAs with the information provided.

The results of each stage of development are provided below.
Three alternative proposals were developed and analyzed using these techniques. The design, which provided the highest level of situational awareness with the minimum workload, was approved for development.

Simulator testing at the Patuxent River Manned Flight Simulator assessed the design for suitability before proceeding into flight test. Several anomalies occurred that could not be definitively traced to the NPA system or the simulator. The basic functionality was deemed acceptable for proceeding into flight test regardless of the manifest anomalies, which did not pose a safety hazard. The decision early in the program to elect for flight tests instead of a full DT provided the flexibility to asses the source of the anomalies and if attributable to flight systems assess their operational impact. The aircrews executed GPS NPA approaches into NAS Patuxent River, in each case the ground tracks were well within the Primary Obstacle Clearance area and accurately followed the required flight path.

Ground and Flight testing was conducted at Patuxent River Naval Air Station. The test aircraft was an HH-1N. The aircraft architecture is depicted in Figure 5, the CDNU architecture is common to 50% of combat and combat support aircraft.
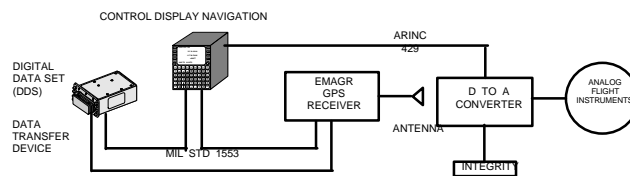

Figure 5.
HH-1N Architecture

Figure 6 depicts typical aircraft approach test results. The boundary is the Primary Obstacle Clearance area. All approaches were flown with the aircraft remaining in the primary obstacle clearance area. The ability to maintain the aircraft within the Primary Obstacle Clearance area validated the overall system design and system requirements.
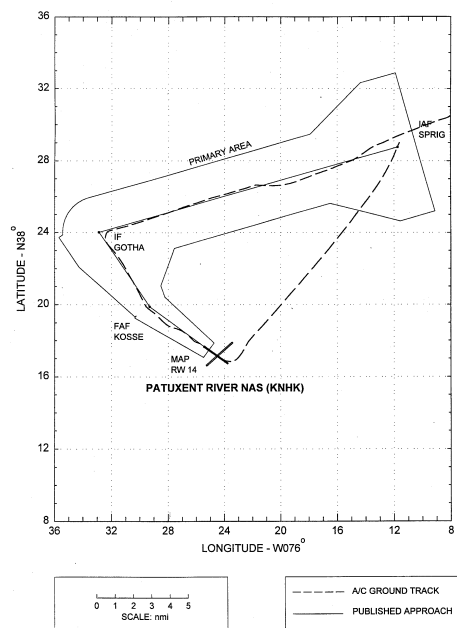
Figure 6.
Approach Results

The simulator and flight test ground tracks were virtually identical with respect to the desired flight path showing remarkable consistency across aircrews.

LESSONS LEARNED

The relations between aeronautical data elements were unclear in the Government documents available at program inception. Attempting to develop software code indicated exactly where problems in interpretation existed. The DAFIF database has since clarified the relations between data in part as a result of lessons learned in the NPA program.

Referencing unavailable documents or failure to provide references, or referencing documents not under your configuration control will insure software errors. The aeronautical database data dictionary must be written in such a way that software developers unfamiliar with aviation and NPA can easily understand it. All the information required in understanding it and coding the software must be in the documents provided to the developer.

Prototype development of complex mission planning software uncouples the software development effort from external schedule pressures, providing sufficient time for identification and correction of software problems.

When clarifications emerged from the database and new functionality was required, the software could be modified without perturbing the overall program schedule.

GPS Precise Positioning System with integrity is capable of meeting the basic integrity requirements. Clear unambiguous interfaces are the most pressing problem with correctly integrating GPS receivers into aircraft.

Aircraft integrators often have only the specifications and ICDs to correctly integrate a system into the aircraft. These documents must be unambiguous to the logical engineer, they should not require the aircraft integrator to become an expert on the internal minute permutations of the Weapons Replaceable Assembly (WRA) to be able to successfully integrate it.

TACAN/VOR/DME stations are generally but not always located near the airport. Aircrews have become accustomed to using the station as a reference to the bearing and distance to the airport. GPS NPAs provide guidance to the next waypoint and not the airport. This is a major paradigm shift. Although not required to execute the procedure, to ease the transition the follow-on CDNU software build will provide bearing and distance to all points in the procedure. The MAP is generally at the runway threshold and will provide information as to the bearing and distance to the airport.

Several problems were detected in flight tests that were unable to be tested during software development. A higher fidelity ground test model allowing the operators full control of the flight path would have uncovered these problems. The selection of a series of flight tests rather than a full DT mitigated their impact. A high fidelity model should be used during the initial stages of testing.

Requiring a final software build with one correction build substantially increases software risk, schedule shortfalls are masked until well into the program when the contractor reports a delay in delivery. To mitigate risk, future software development efforts will require periodic software deliveries. The periodic deliveries indicate early in the program contractor's progress and software maturity. Each software delivery will be tested against the requirements, providing sufficient time to correct problems.

REQUIRED CHANGES

The DAFIF dictionary is being upgraded to document how to correctly code the assembly of the approach and departure procedures.

The GPS Common Mission Data Loader Cartridge Format Specification has incorporated the necessary changes to support the transfer of GPS NPA procedures.

The GPS Functional Requirements Document is in review specifying the GPS NPA flight planning requirements.

The CNO GIG is being revised to permit the use of GPS PPS as a Primary Means of Navigation from Take-off through enroute recovering to GPS NPA minimums.

The CNO GIG modifications to reflect the new requirements, provides the means to certify aircraft as compliant and interoperable with civil systems (RNP).

Upgrading CDNU-MAGR platforms with GPS as a primary means of navigation requires replacement of the MAGR with a MAGR 2000 (form, fit, function compatible with MAGR plus integrity), loading new CDNU software into the CDNU and providing an integrity annunciator in the primary field of view. 3a-CDNU aircraft's additional change is converting the integration from a 3a to a MAGR 2000, which includes new mounts and modification of aircraft wiring.

MAGR-Mission Computer aircraft require replacing the MAGR with a MAGR 2000, new mission computer software and modified displays.

3a-Mission Computer aircraft require replacement of the 3a by a MAGR 2000, modification of the mission computer software and displays.

EGI based aircraft will require the incorporation of integrity into the aircraft's integration and the appropriate software and displays.

N-PFPS software is under development to support the downloading of GPS NPA procedures to the Data Transfer Module, which is the mechanism for loading the information into the aircraft.

CONCLUSIONS

GPS NPA can be integrated into DoN aircraft without requiring major redesign of the aircraft integration. All the elements are in place and proven solutions are on hand.

The PMW/A-187 common architecture supports growth to meet the evolving needs of military aviation in a cost effective manner.

THE ROAD AHEAD

The MH-53E is the Navy's lead platform for GPS as a primary means of navigation, Operational Testing to occur in late 2000. Follow-on CDNU-MAGR aircraft will be qualified by similarity, Developmental Test only, Operational Test not required. MAGR-Mission Computer aircraft will require a MAGR with integrity, e.g. MAGR 2000 and an upgrade to their mission computer/display system. A full DT and OT will be required on the Mission Computer/MAGR aircraft. 3a-CDNU aircraft will require a full DT and OT for their lead aircraft, with follow-on aircraft being qualified by similarity. 3a-Mission Computer aircraft will require full DT and OT on each Type/Model/Series aircraft. Presently due to the unavailability of funding no upgrades are planned for any aircraft other than the MH-53E.

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